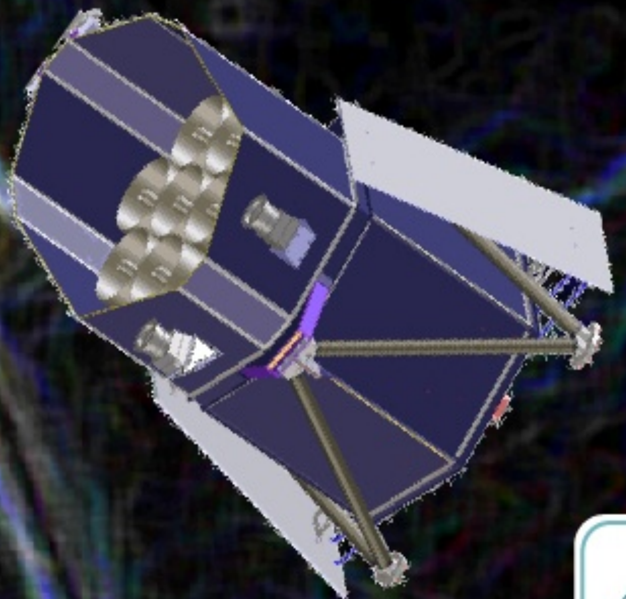
Studying Neutron Stars

with

IXO

and

eROSITA



W.Becker

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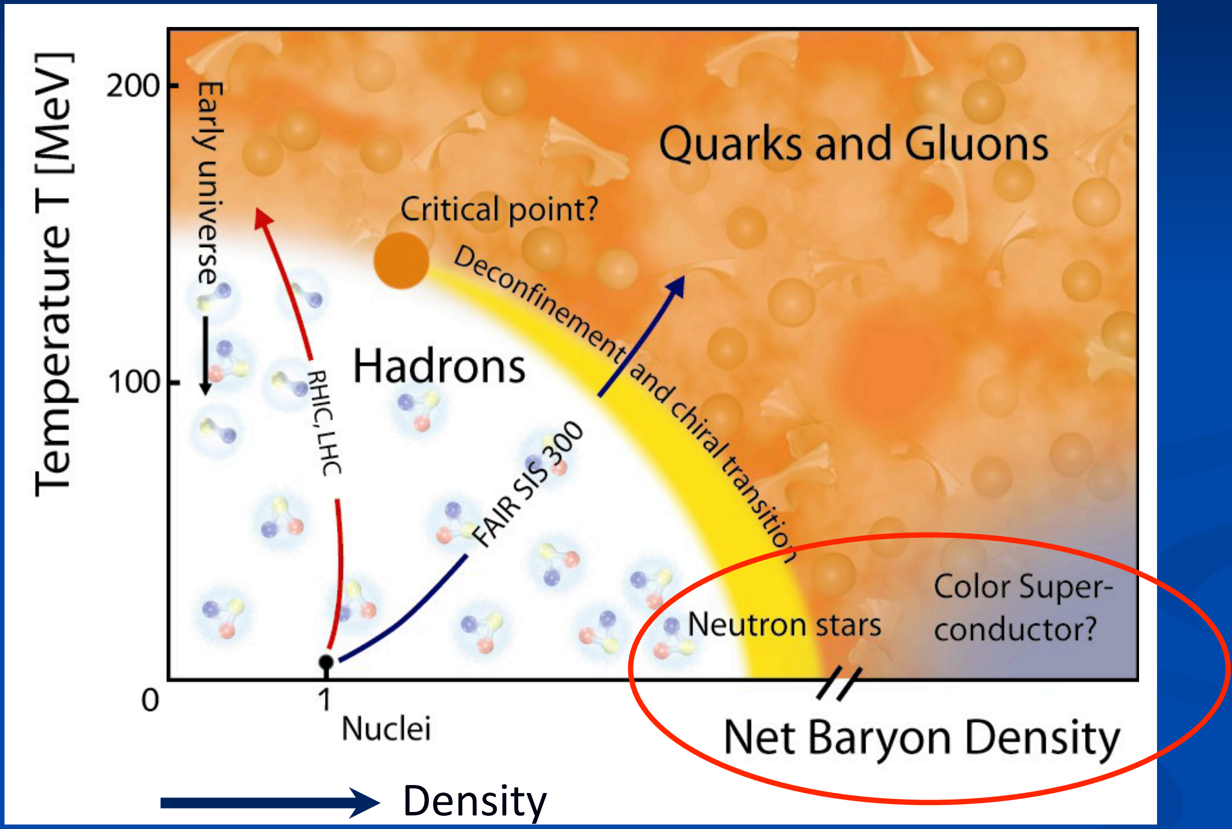
Neutron stars are the most compact objects which can be studied through direct observations (BHs can be observed only indirectly)

Extreme stellar parameters:

Mass	1,4 solar masses
Radius	10 km
Density	> 500 Million tons per cm^3
Gravitation	10 Billion g
Magnetic field	100 Billion Gauss
Rotation period	down to Milliseconds

- Neutron stars are quasi "Gigantic Atomic Nuclei" in the universe
- What can we learn from studying these objects ?

Neutron stars probe the low temperature -- high density region of the QCD phase diagram

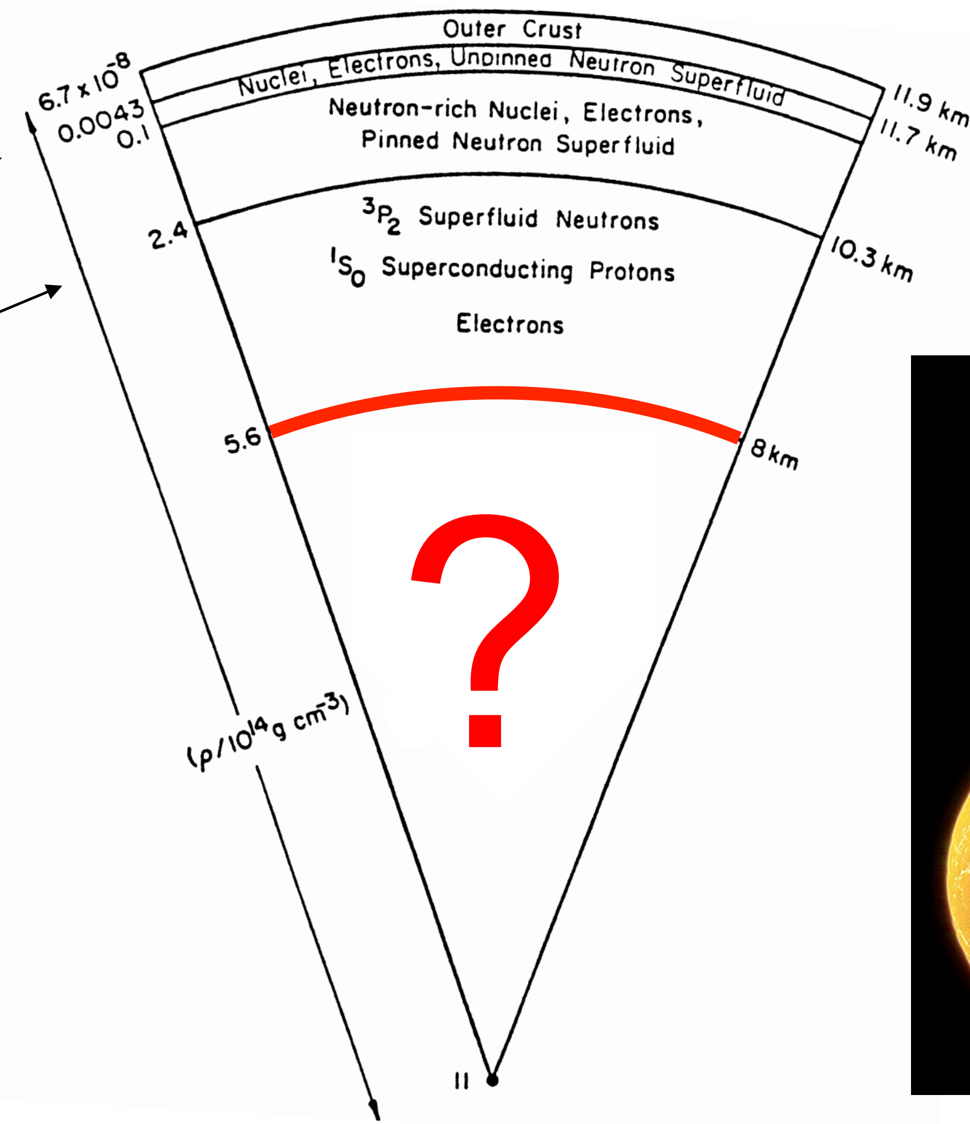


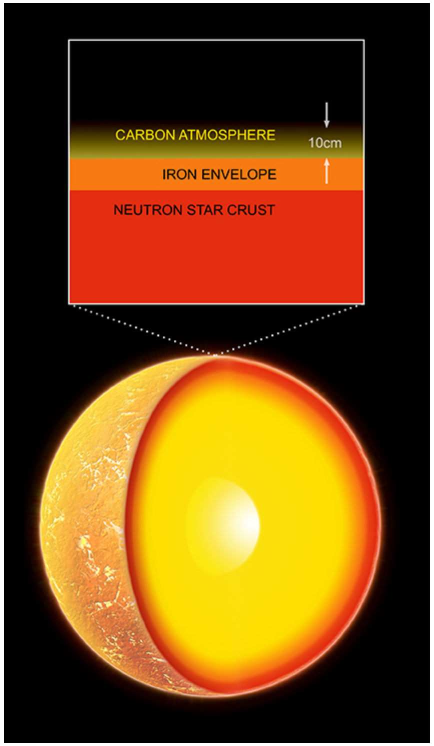
→ Equation Of State of cold nuclear matter at high density ?

Slice plane through a 1.4 Mo Neutron Stars

Neutron drip point

Nuclear density

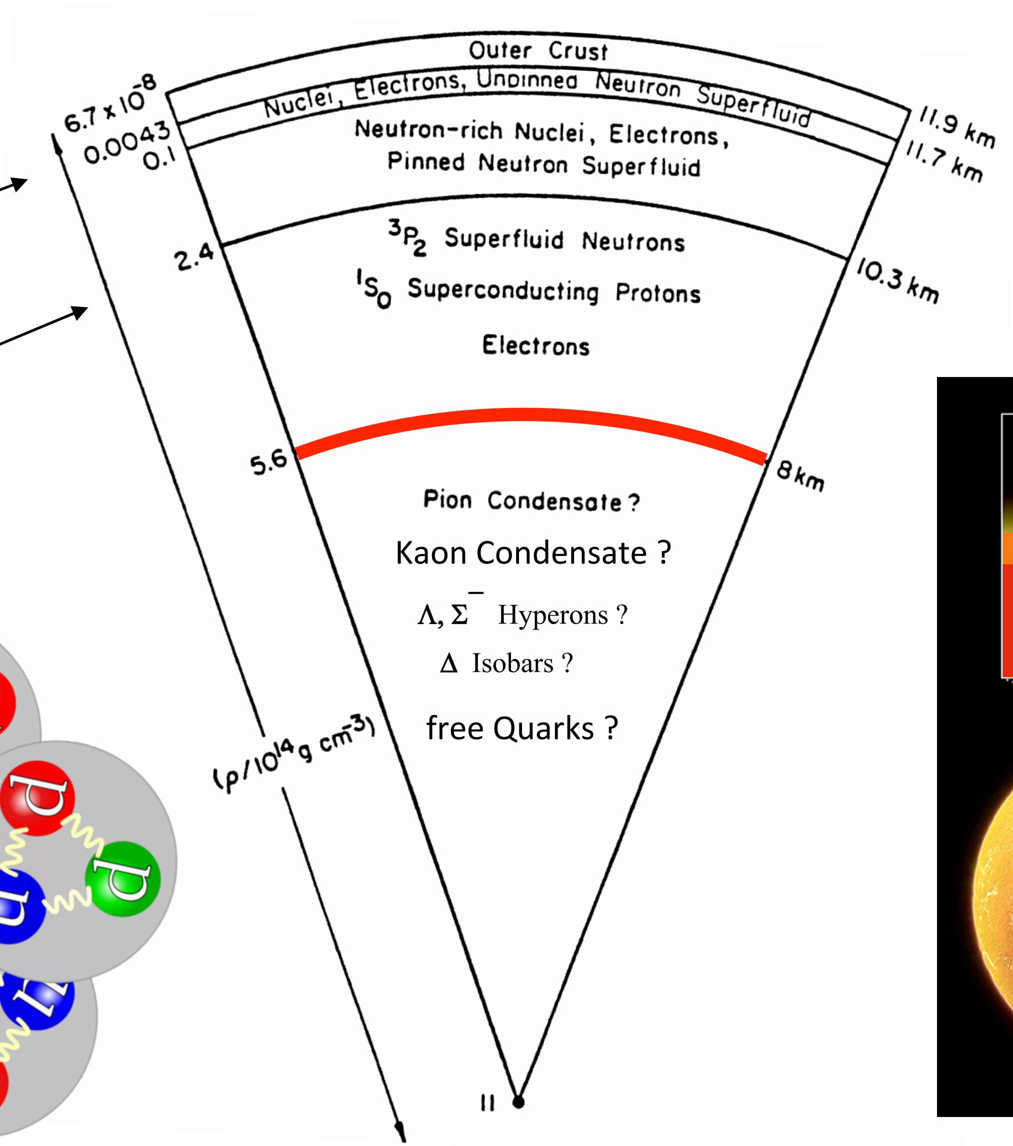


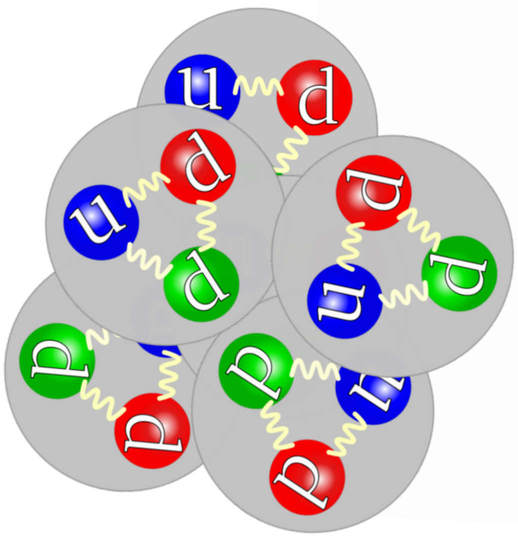


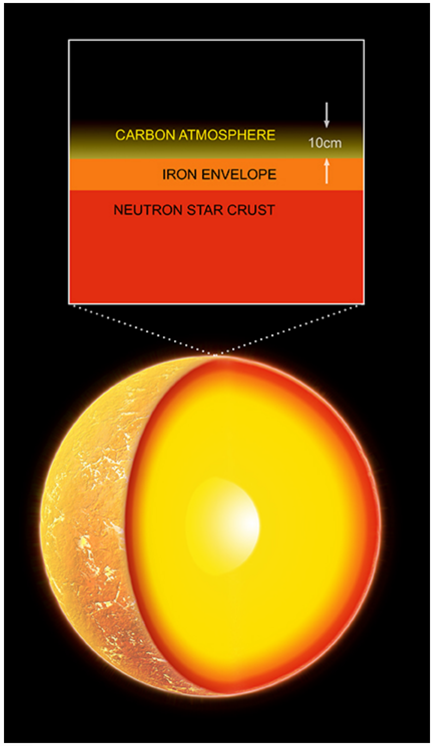
Slice plane through a 1.4 Mo Neutron Stars

Neutron drip point

Nuclear density







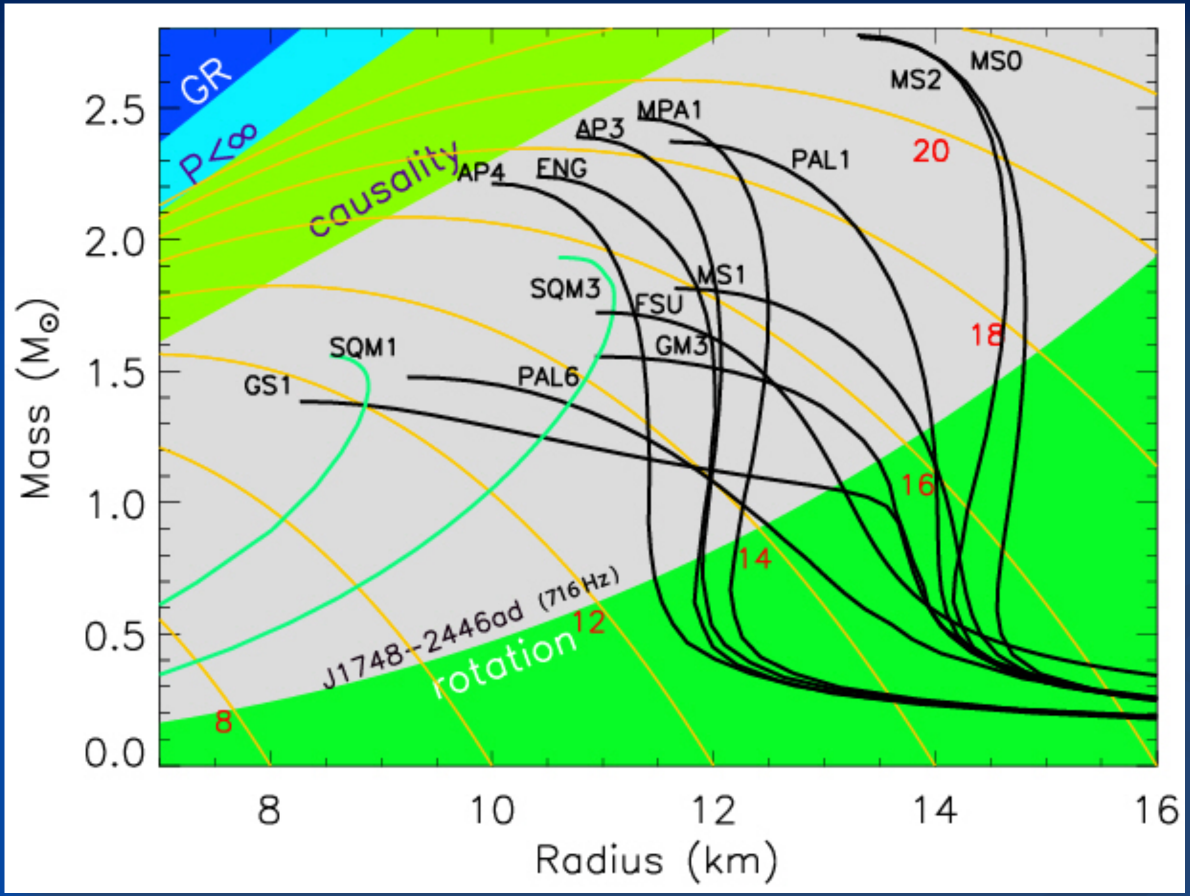
Equation of state (EOS) of nuclear matter

The key to get this right is the neutron star EOS!

The EOS can be translated into a

Mass-Radius relation: $M = M(R)$

Equation of state of nuclear matter

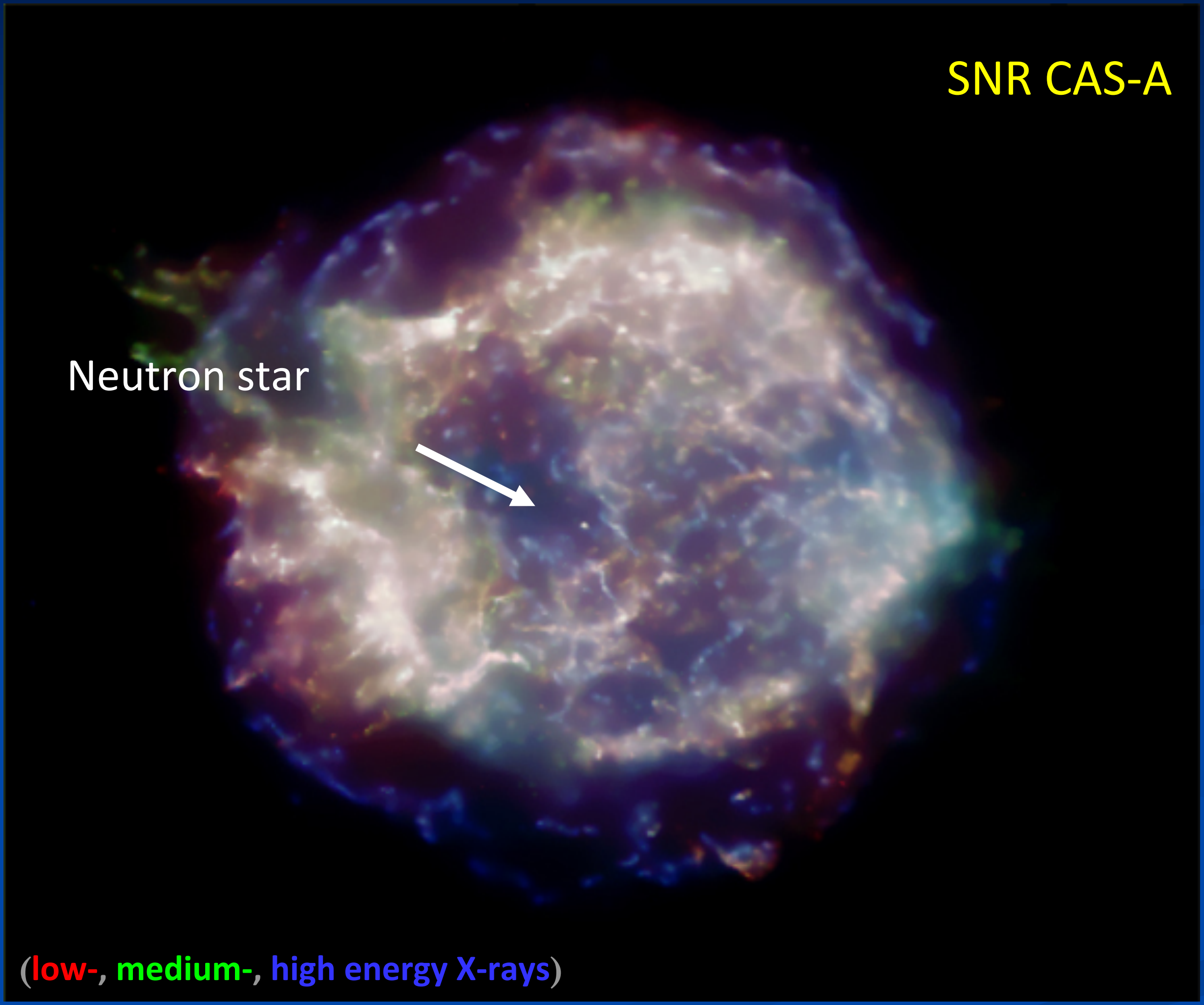


Lattimer 2007

It is required to measure M and R of the same object in order to constrain its EOS

IXO on
Cooling Neutron Stars and on
10^7 years old pulsars

Neutron stars represent an endpoint of stellar evolution



NSs have a temperature in the million degree range → spectrum peaks in X

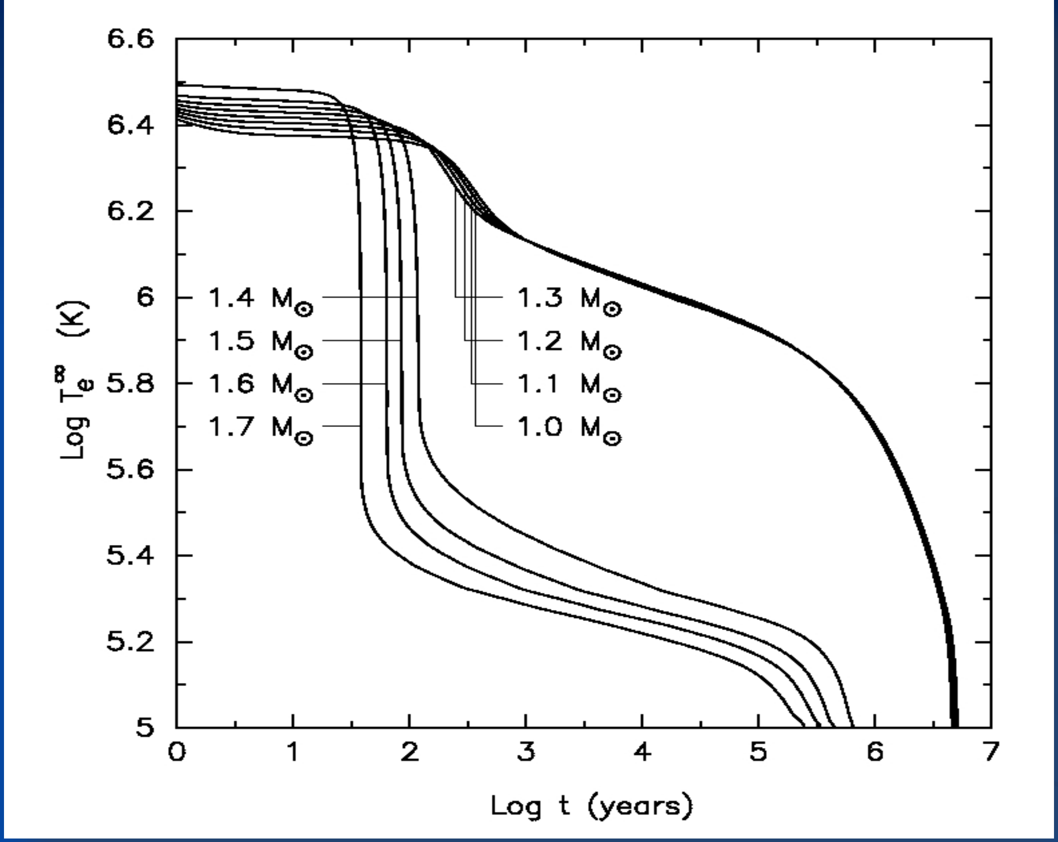
Neutron Star Cooling

$$\frac{dE}{dt} = C_v \frac{dT_i}{dt} = -L_\nu - L_\gamma + \sum_k H_k$$

The details on neutron star cooling depend strongly on the neutron star EOS, i.e. on the interaction of the particles sustaining the star

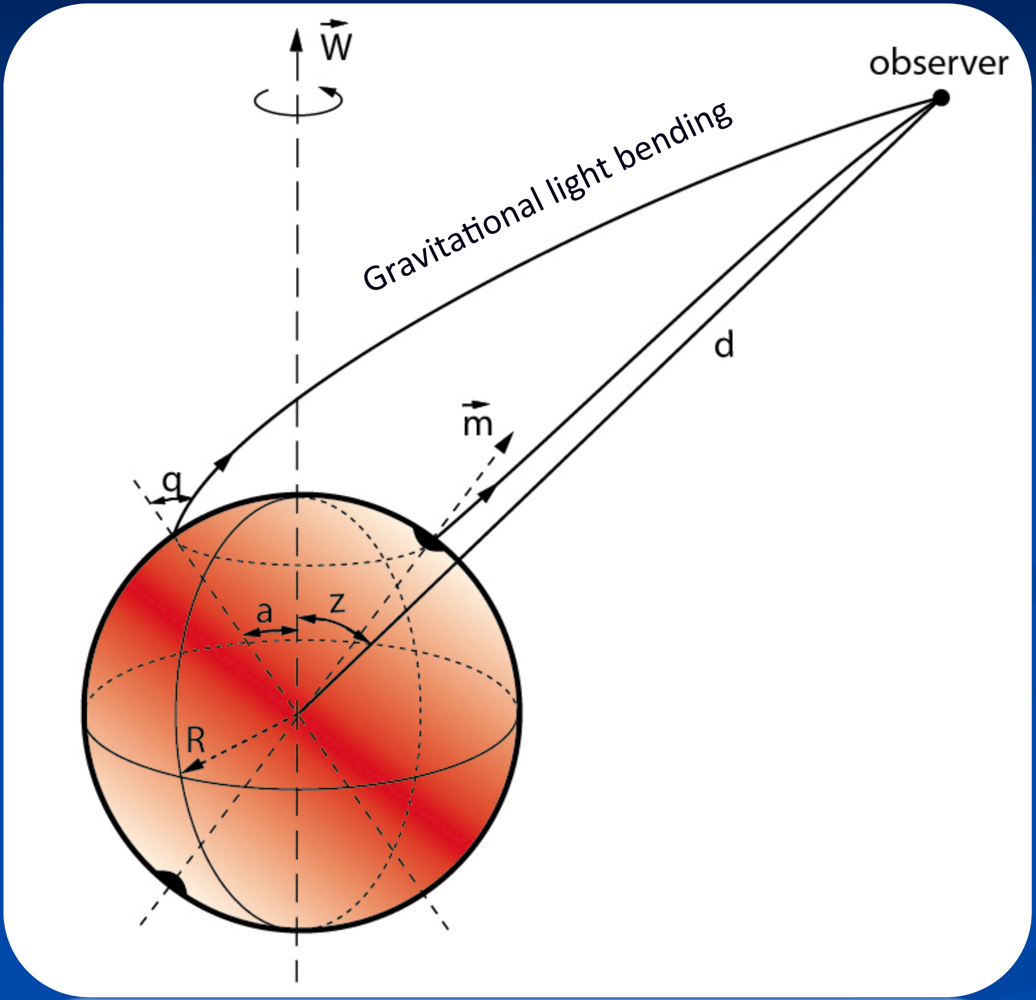
Neutron star cooling is sensitive to the EOS of cold dense mater !

Neutron Star Cooling ← → EOS of cold dense nuclear mater



Observing thermal spectra from neutron stars yields the surface temperature AND the emitting area and hence its <u>radius → R</u>

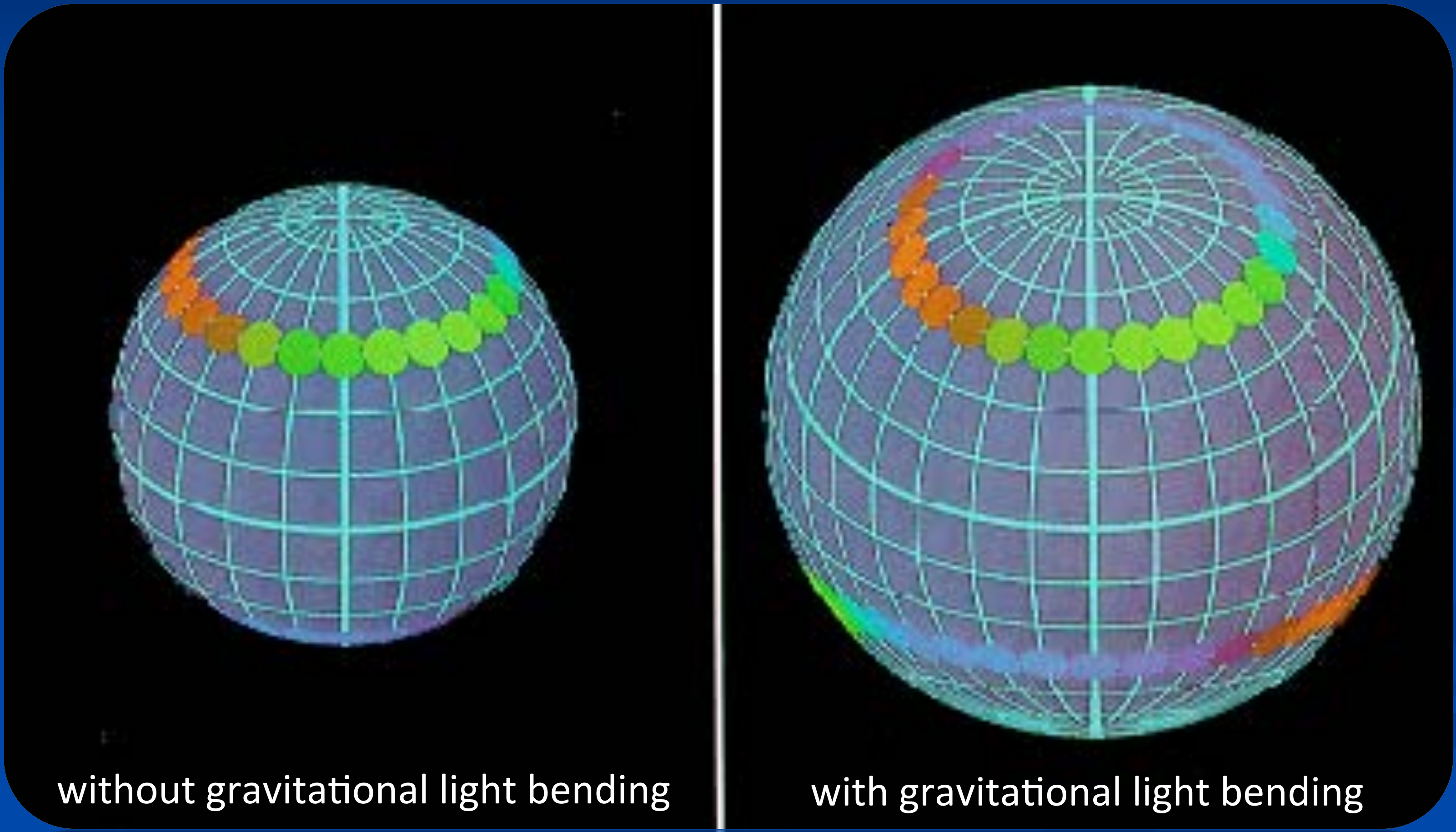
Gravitational light bending effects depend on M/R



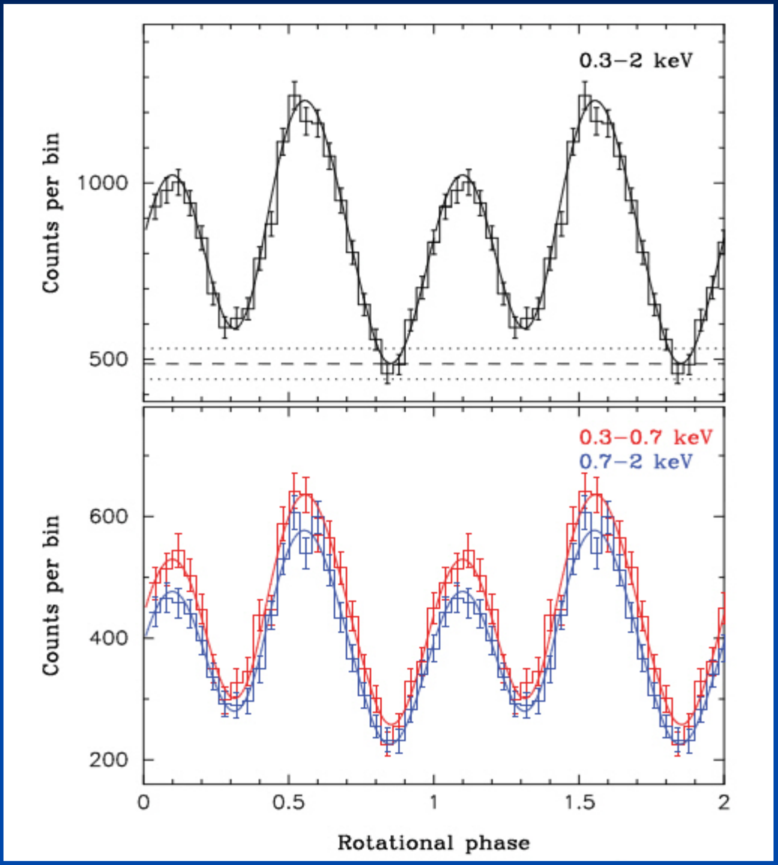
Details depend on **M/R** and have an measureable impact on the observed pulse shape

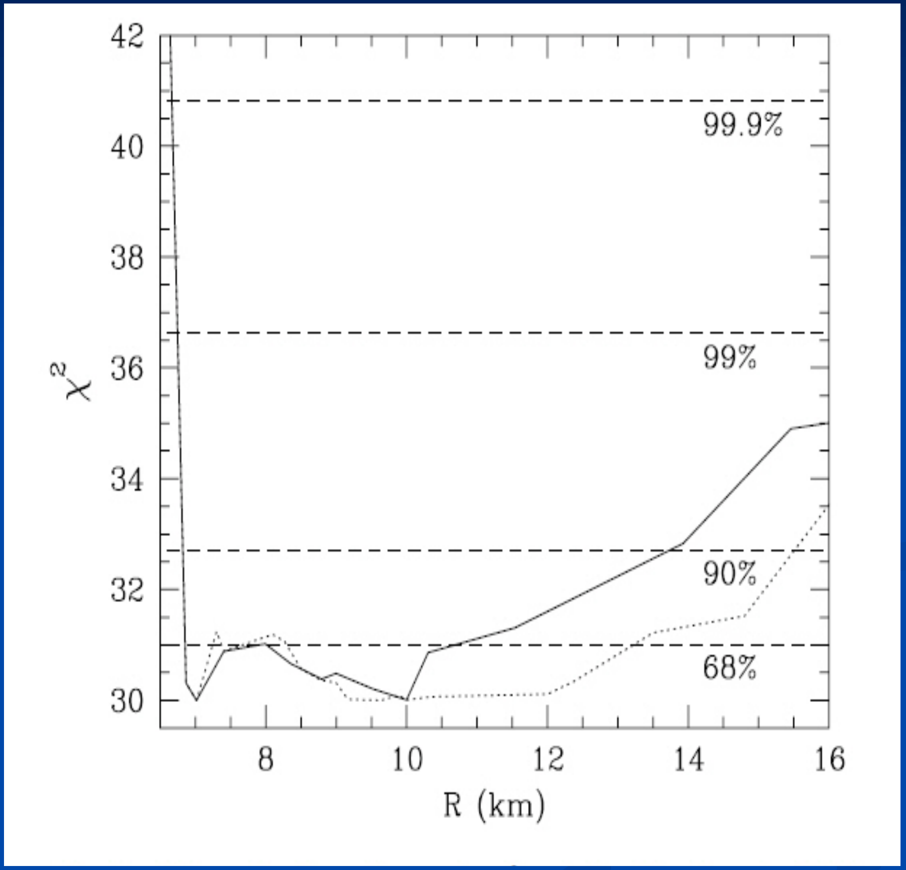
Becker 2009

Gravitational light bending effects depend on M/R and have an measureable impact on the observed pulse shape



Pulsar waveform fitting is sensitive to the neutron star's M/R





Requires extremely good photon statistics

to yield meaningful results → need for an observatory like IXO

Neutron Star Cooling ← → EOS of cold dense nuclear mater

Neutron star cooling…..

$$\frac{dE}{dt} = C_{\mathrm{v}} \frac{dT_i}{dt} = -L_\nu - L_\gamma + \sum_k H_k$$

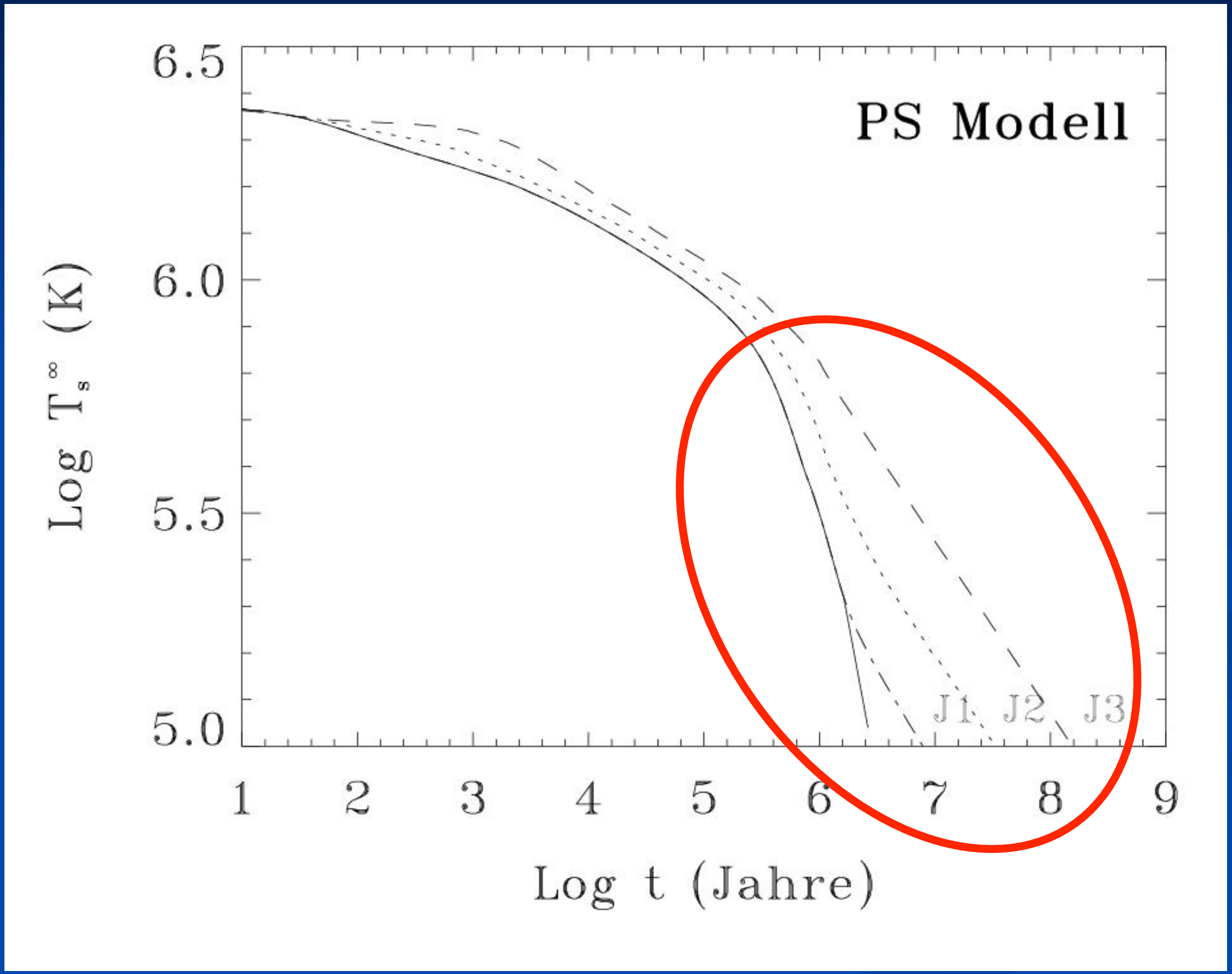
C_{v} : Specific heat capacity

L_ν : Neutrino luminosity

L_γ : Thermal luminosity

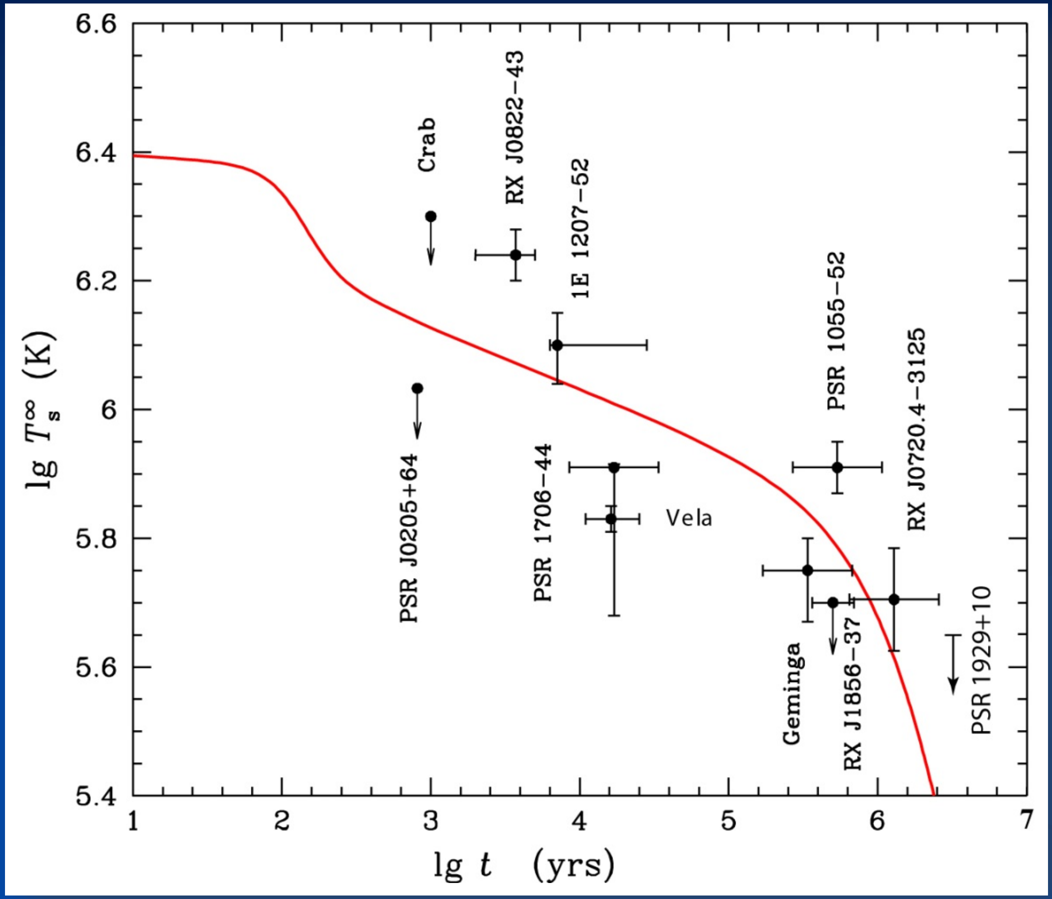
$\sum_k H_k$: Neutron star heating by e.g. vortex creep of superfluid neutrons or roto-chemical heating

Neutron Star Cooling ← → EOS of cold dense nuclear mater



Neutron star cooling depends on heating rates

Neutron Star Cooling ← → EOS of cold dense nuclear mater



Temperatures have been measured for young and middle-aged pulsars but only old pulsars can constrain heating rates which depend on micro-physics inside neutron stars

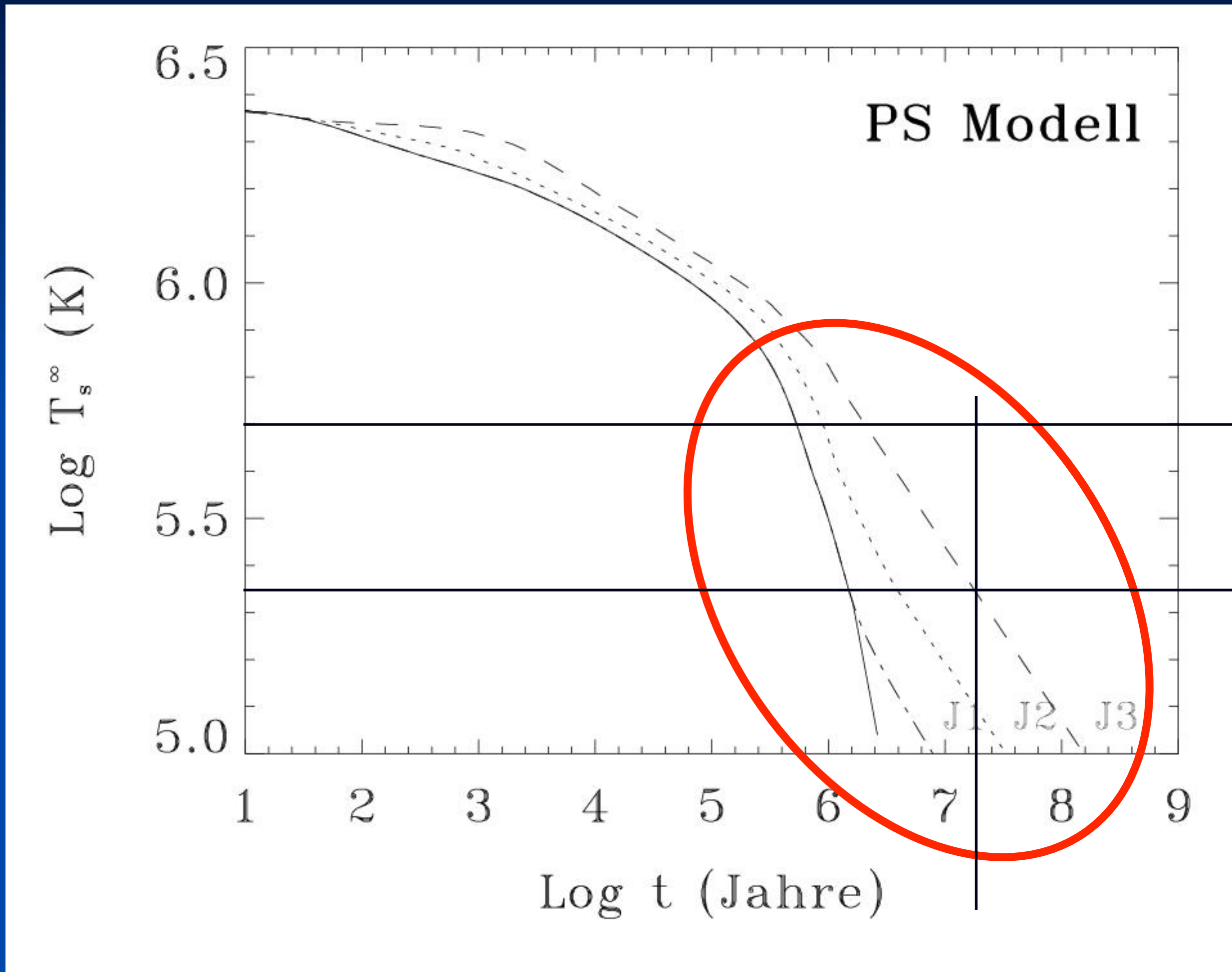
Surface temperatures for 10^7 years old Pulsars

R_{NS}=10 km

Pulsar	Spin down age	T_S^∞ 3σ upper limt
B2224+65	1.13 x 10^6 yrs	< 0.68 10^6 k
J2043+2740	1.2 x 10^6 yrs	< 0.62 10^6 k
B0628-28	2.75 x 10^6 yrs	< 0.53 10^6 k
B1929+10	3.1 x 10^6 yrs	< 0.45 10^6 k
B0823+26	5 x 10^6 yrs	< 0.5 10^6 k
B0950-09	17 x 10^6 yrs	< 0.48 10^6 k

Becker 2009

Neutron Star Cooling ← → EOS of cold dense nuclear mater



Upper limit from XMM

Surface temperature which can be measured by IXO in 50 ksec for e.g. PSR 0950-09 (d=250 pc)

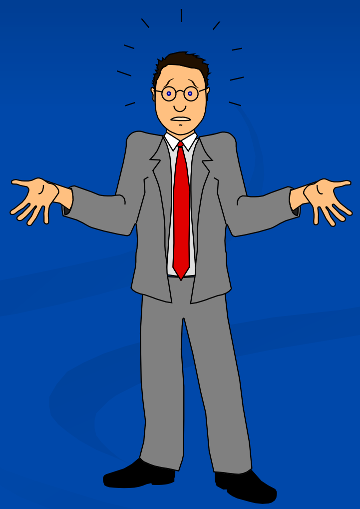
IXO will be able to challenge neutron star cooling models and reheating scenarios

Open Questions .....

General:

- How are the different manifestations of neutron stars related to each other?
- What decides that a collapsing star will end in a Crab-like pulsar, a Magnetar or a CCO ?

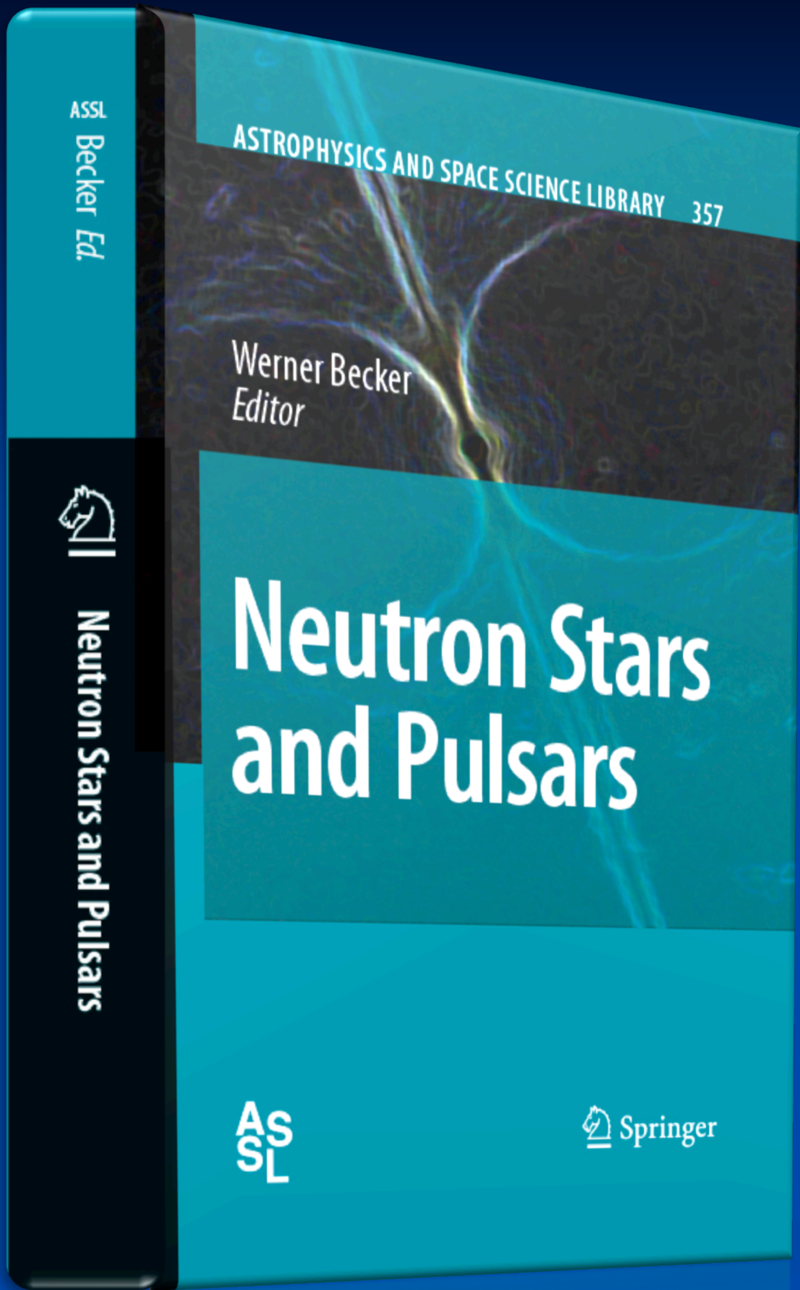
EOS:



- What is the maximal upper bound for a neutron star mass ?
- What is the range of possible neutron star radii ?
- Is there any exotic matter in neutron stars (do strange stars exist) ?

Emission Process:

- How can we relate e.g. the spectra observed at radio, optical, X- and gamma-rays to get a general understanding of the emission processes operating in the neutron star's magnetosphere ?



springer.com

ASSL 357

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Neutron Stars and Pulsars

Written for students, post-docs and professionals

Keywords:
- Gravitational Waves from Spinning Neutron Stars
- Isolated Neutron Stars and Millisecond Pulsars
- Neutron Star Cooling and Magnetic Field Evolution
- Particle Acceleration and Interactions in Pulsar Magnetospheres
- Pulsar Wind Nebulae
- Radio and high Energy Emission from Rotation-Powered Pulsars
- Soft Gamma-ray Repeaters and Magnetars
- Structure of Neutron Stars and EOS

"What have we learned about the subject and how did we learn it?"

"What are the most important open questions in this area?"

"What new tools, telescopes, observations, and calculations are needed to answer these questions?".

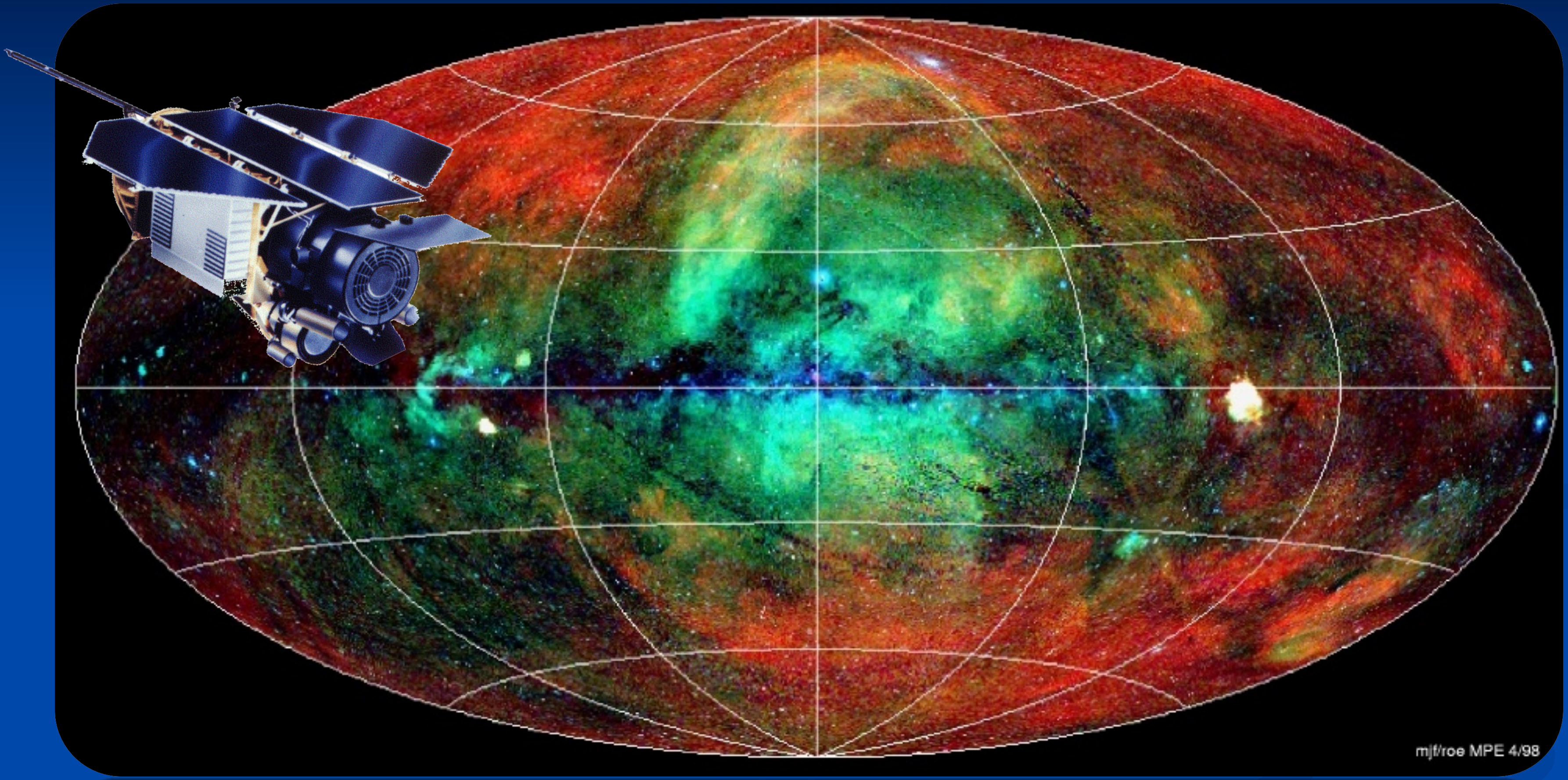
With contributions from:
D.Lorimer, R.N. Manchester, M. McLauglin, A.G. Lyne, M. Kramer, W. Becker, R. Turolla, J. Grindlay, V.E. Zavlin, F. Weber, D. Page, S. Tsuruta, U. Geppert, M. Ruderman, J. Arons, J. Kirk, O.C. de Jager, K.S. Cheng, A.K. Harding, J.M.E. Kuipers, K. Hurley, M. Weisskopf, D.A. Smith, D.J. Thompson, R. Prix

eROSITA: Launch date ….

Nov. 20th / 16:45

2012

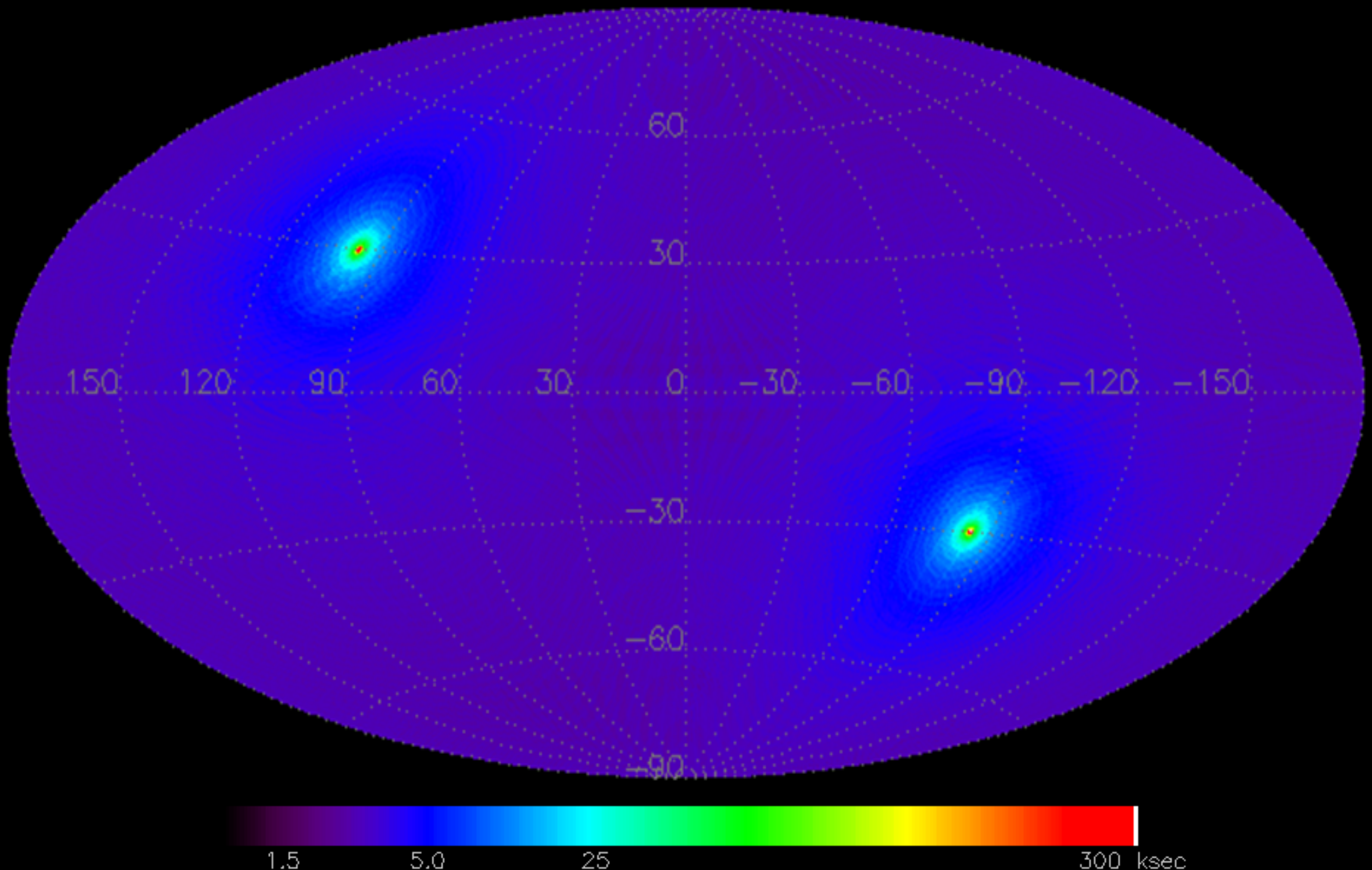
Basic Scientific Idea ….



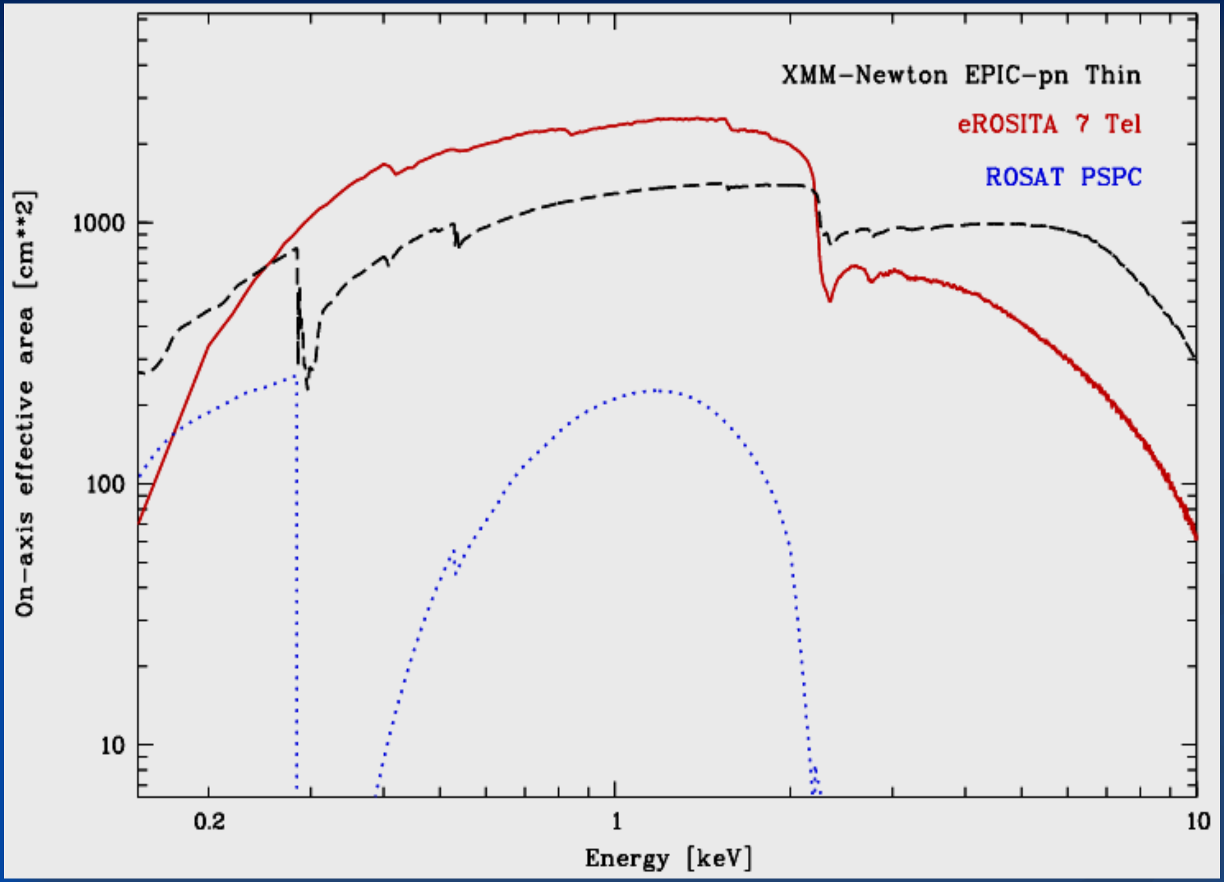
to extend the ROSAT all-sky survey up to 12 keV
with an XMM type sensitivity

eROSITA: Exposure Map

~ 3-5 ksec in the plane



eROSITA: effective area 2400 cm^2 @ 1keV



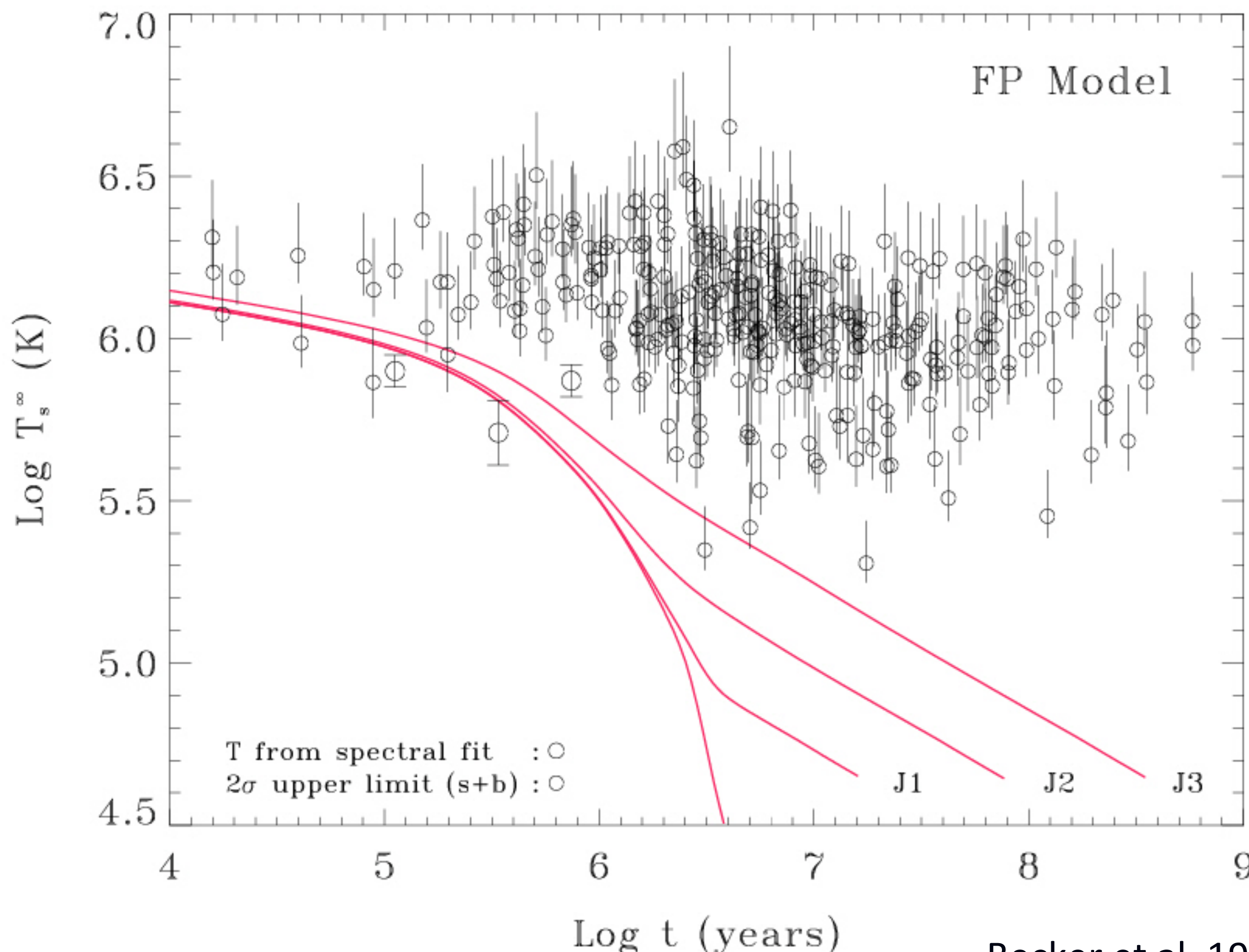
Survey sensitivity 10 – 30 times that of ROSAT

How many pulsars will be detected in the all sky survey?

Survey duration	Detections
½ year	43
1 year	55
1 ½ year	66
2 years	72
2 ½ years	82
3 years	90
3 ½ years	93
4 years	~100

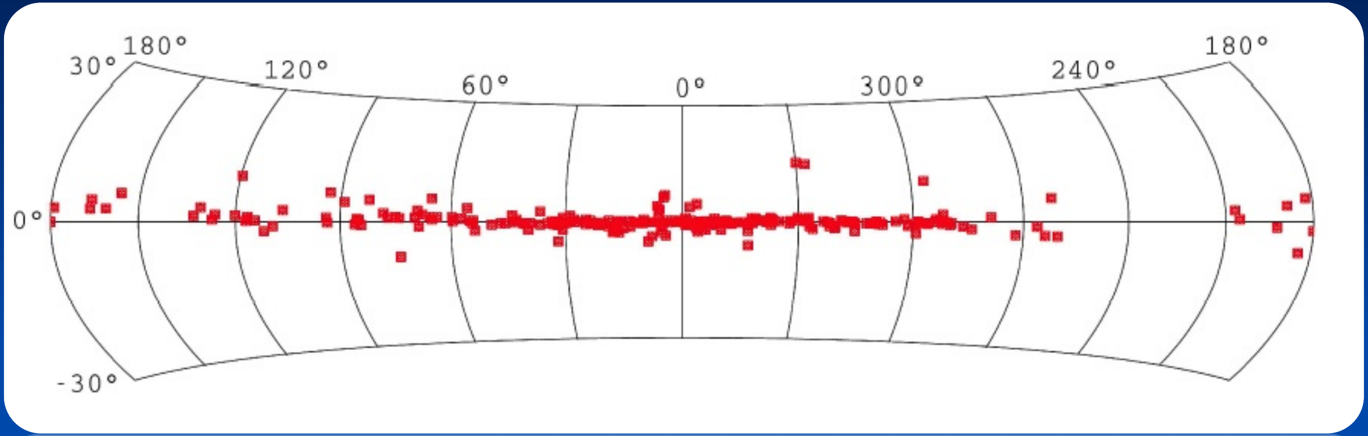
All pulsars will be detected with a photon statistics sufficient to perform a detailed spectral and timing analysis !

Temperature upper limits for all neutron stars in the survey



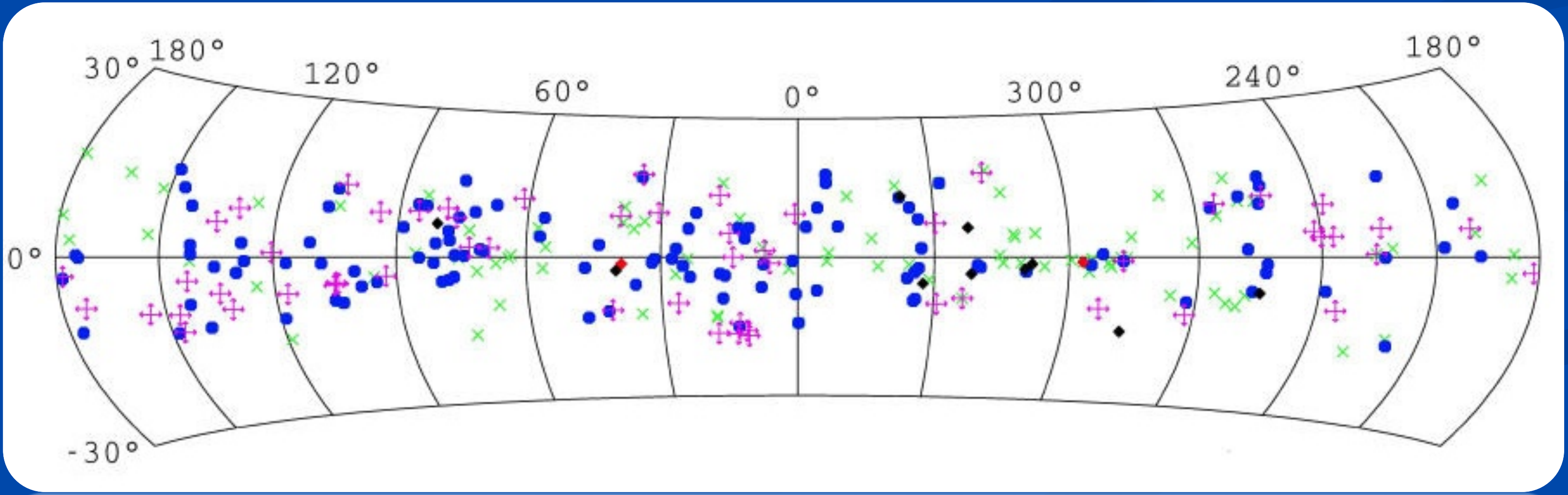
Becker et al. 1995

eROSITA will also be great on supernova research …

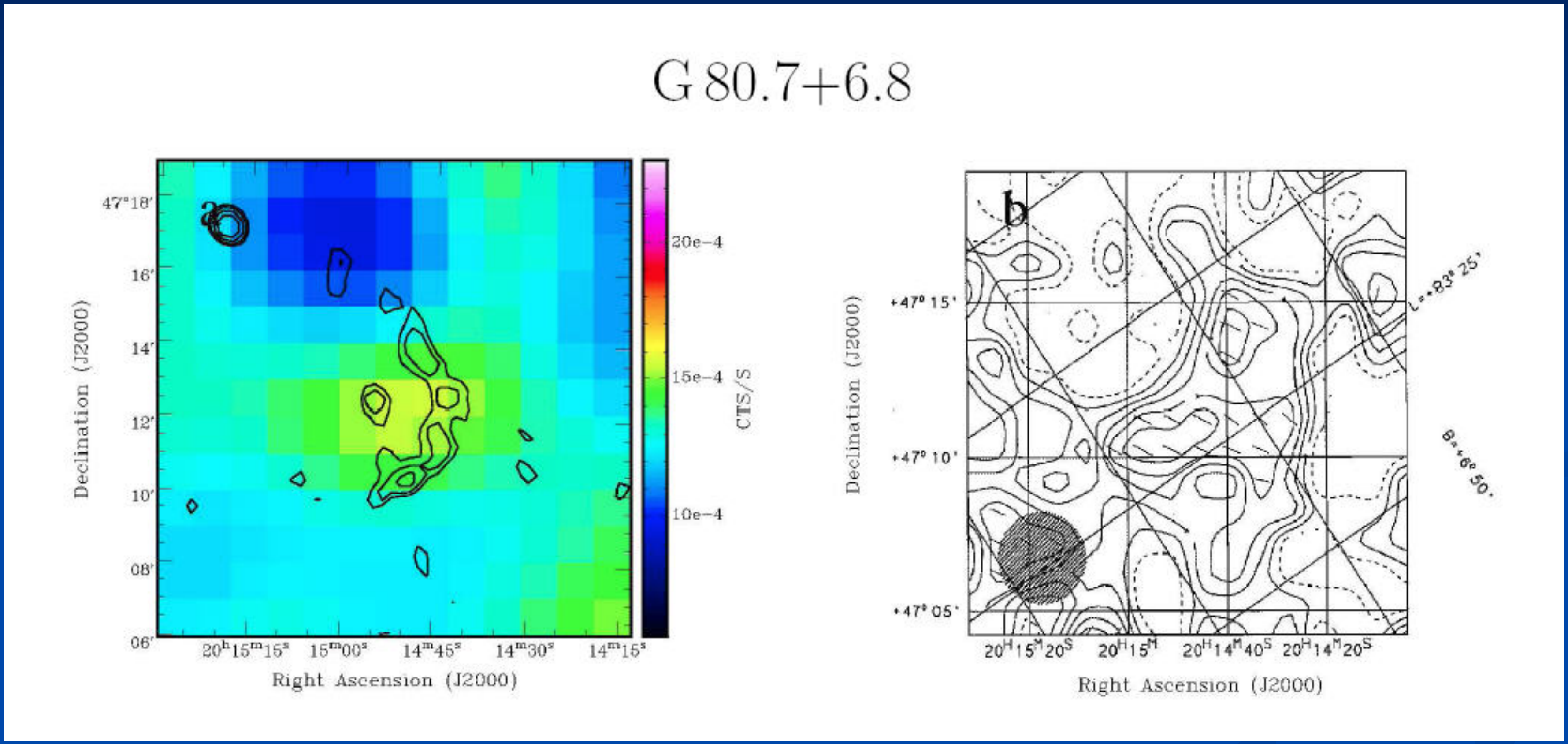


~270 known Galactic SNRs

RASS: 215 SNR candidates



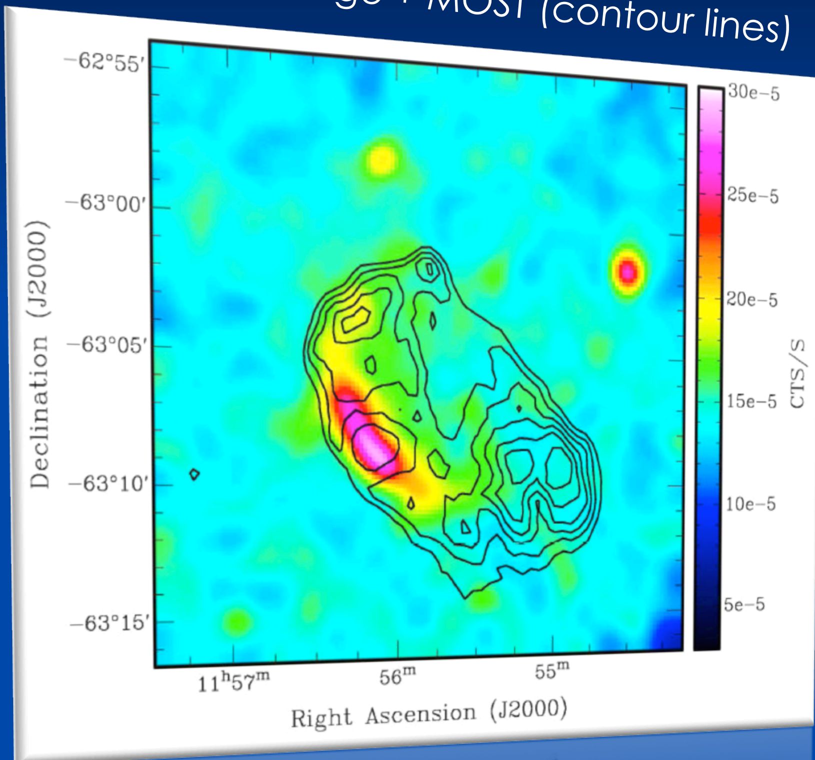
Supernova remnant candidates in the RASS



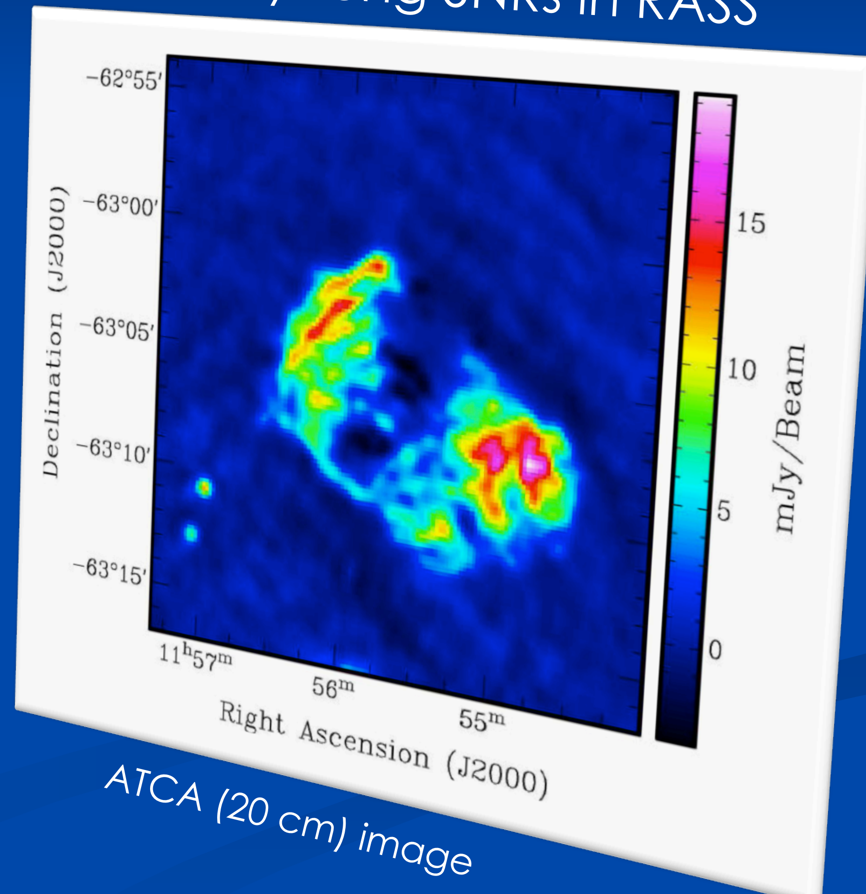
Supernova remnant candidates in the RASS

G296.7-0.9

ROSAT RASS image + MOST (contour lines)

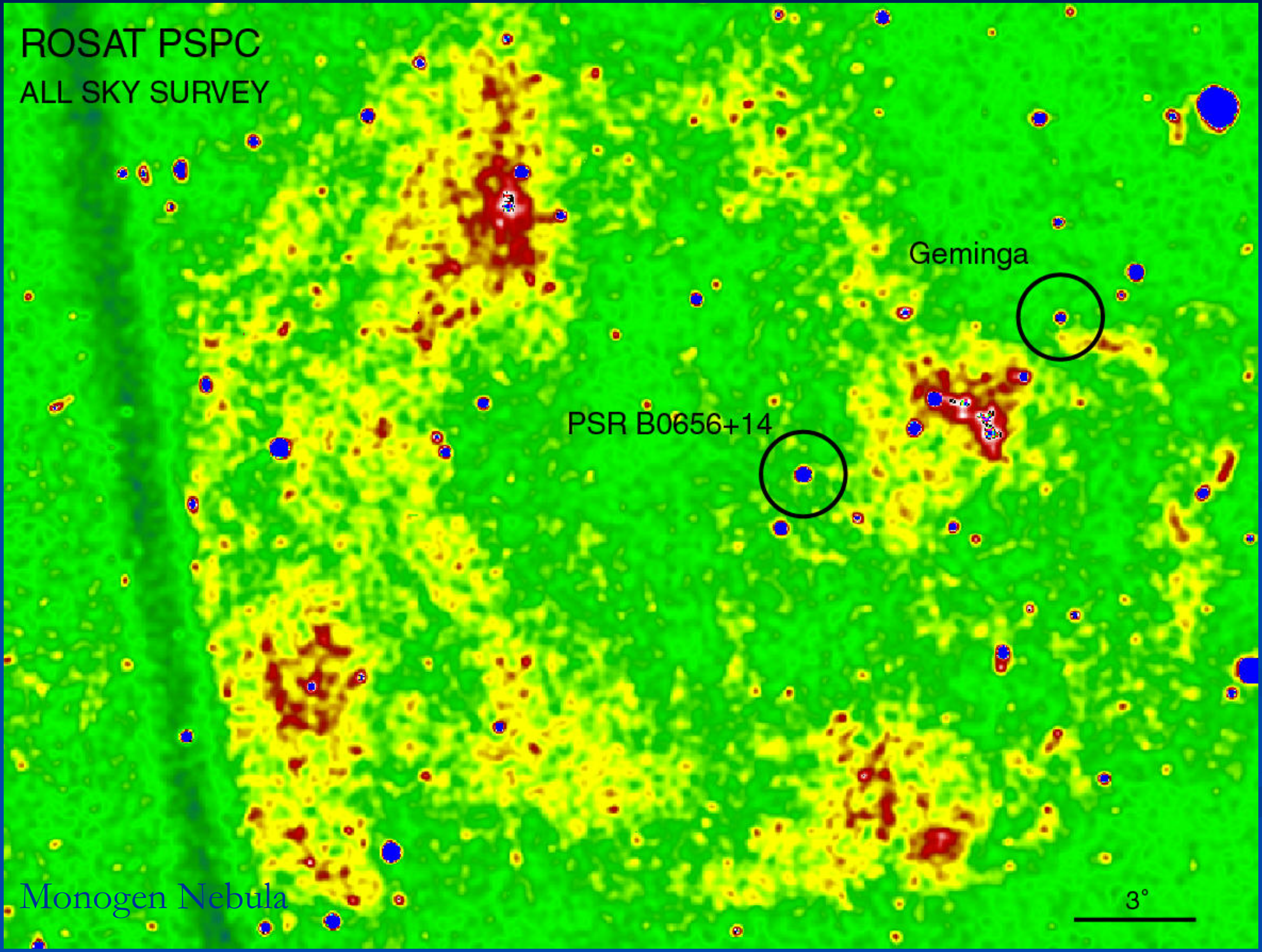


new young SNRs in RASS



ATCA (20 cm) image

eROSITA on large supernova remnants



Conclusion …

… with the new more sensitive facilities

eROSITA & IXO

the future of neutron star astronomy

and SNR research is bright!